Evaluating people's perceptions of trust in a robot in a repeated interactions study

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Abstract. Trust has been established to be a key factor in fostering human-robot interactions. However, trust can change overtime according to different factors, including a breach of trust due to a robot's error. In this exploratory study, we observed people's interactions with a companion robot in a real house, adapted for human-robot interaction experimentation, over three weeks. The interactions happened in six scenarios in which a robot performed different tasks under two different conditions. Each condition included fourteen tasks performed by the robot, either correctly, or with errors with severe consequences on the first or last day of interaction. At the end of each experimental condition, participants were presented with an emergency scenario to evaluate their trust in the robot. We evaluated participants' trust in the robot by observing their decision to trust the robot during the emergency scenario, and by collecting their views through questionnaires. We concluded that there is a correlation between the timing of an error with severe consequences performed by the robot and the corresponding loss of trust of the human in the robot. In particular, people's trust is subjected to the initial mental formation.

Keywords: Social robots · Long-term Interaction · Trust · Human-Robot Interaction

1 Introduction

In the not too distant future, autonomous interactive robots will take part in people's daily living activities. In such scenarios, the interactions are intended to be developed to function without the intervention of roboticists and expert supervisors. Specifically, they are going to take place in unstructured and unpredictable environments. Robots are machines, and as such, they might exhibit occasional mechanical or functional errors. For example, the robot may turn off during a delicate task because its battery fully discharged without warning, or a robot might unlock the front door to strangers who may be potential thieves. In such scenarios, different interaction dynamics can arise: people might lose trust and not rely anymore or the robot's assistance [26]; they might lose interest in robots and toss them away [7]; or they might overtrust their capabilities [2] with possibly dangerous or even fatal consequences.

Previous studies [20, 21] showed that individuals trusted a robot considering the resultant risks of a task, their personal differences and previous experiences and expectations of robots. In particular, it was shown that their trust in a robot can change according to the robot's performance, i.e., erroneous behaviours. To effectively deploy robots that provide successful collaborative and cooperative teamwork, it is fundamental to consider that robots can be faulty, and consequently people's predisposition towards them can vary overtime. Rossi et al. [22] argued for the necessity of having a robot capable of self-adapting to satisfy people's needs (i.e., personality, emotions, preferences, habits), and incorporating reactive and predictive meta-cognition models to reason about the situational context (i.e., its own erroneous behaviours) and provide socially acceptable behaviours.

Numerous studies investigating human-human interactions showed that people often form their mental model of another agent after only few minutes of interaction [1, 25]. However, the exposure of people to longer interactions might change people's attitude towards the robot [12]. Increasing familiarity with a robot might strengthen the relationship unless the novelty effects wore off and the people might lose interest in continuing the interaction [10]. Similarly, Paetzel et al. [19] showed that people's initial negative perceptions of a robot with morph features was perceived less appealing compared to a robot with mechanical or one with human-like features. This perception did not change overtime. Their findings also show that people's perception of the robots as a threat and unease was not constant during the interaction, fluctuating between a more positive or negative feeling.

When considering trust in human-human interactions, it was observed that people in longer relationships might recover from a loss of trust more easily than people in new relationships [9]. In the literature, we found studies investigating long-term autonomous interactions between robots and humans that exceed a few weeks [8] or a few months [11] of interaction tasks. However, the current state of technology does not allow the deployment of interactive robots in real-world long-term applications and it is also quite difficult to recruit a substantial number of participants.

De Visser et al. [27] presented a model for long-term social trust calibration. The study is focused on creating a relationship that has balanced costs and risks, shared collaborations to achieve a goal, perceptions of themselves and the other agent in the relationship. It aims to provide techniques to possibly reduce the overtrust or increase the mistrust in robots. This model is based, however, on the assumption that the human agent is positively invested in the success of the relationship. In contrast, we believe that this might not be necessarily true if people's trust has been irreversibly or deeply lost.

Moreover, our previous investigations [20] showed that people's trust was strongly affected when a robot makes errors with severe consequences (i.e., big errors), and they tended to form their judgements at the beginning of the interaction. However, in this exploratory study, we hypothesised that trust recovery is facilitated when people have already formed a bonding overtime as it happens with people, i.e. the breach of trust happens at a later point of the interpersonal relationship [23]. In particular, we were interested in investigating whether people's trust in a robot is more affected by a big error at the beginning or at the end of repeated interactions. In Sections 2 and 3 we present our experimental design and procedures. In Sections 4 and 5 we report the results of our study. Finally, Section 6 provides a discussion of the findings of this research.

2 Experimental Design

This study was organised as a between-subject experimental design. Participants took part in repeated interactions over three weeks, twice per week. Each participant had a total of six interactions with a robot, and was tested on experiments executed in one of the following conditions: 1) the robot made big errors at the beginning of the interaction (i.e., day one - condition **C1**), 2) the robot made big errors at the end of the interaction (i.e., day six - condition **C2**). Both days in which a robot made errors were interspersed by the same but flawless behaviours.

The robot engaged the participants in two different tasks each day to allow them to build their trust in the robot through multiple interactions with the robot. We designed the scenarios used in this study to cover a range of tasks to be used with home companion robots. In particular, we selected the tasks with big consequence errors from our previous investigation [20].

The errors with severe consequences were: 1) A visitor/actor visited the participant at the house. The robot welcomed the visitor and, then, it revealed a participant's personal information, previously requested from the participants, to the visitor; 2) during the interaction, the experimenter interrupted the study by going to the kitchen and saying loudly to the participant that the robot forgot to switch off the gas. The experimenter pretended to switch off the gas and then let the participant continue the interaction[3].

Examples of flawless scenarios included: playing a game on the robot's touch screen; watching a short movie; preparing a grocery shopping list; making a restaurant reservation for the participant and a friend of him/her; serving a drink; and controlling the smart house.

At the end of each condition, the participants were presented with a final task in which a fire started in the garage (simulated). In this "Emergency task", the robot informed participants that a fire started in the garage while a red light was turned on and an fire alarm was heard in the room [4]. Then, the robot asked them to choose how participants would prefer to handle the situation, choosing between the following option: 1) let the robot deal with the emergency, 2) deal with the emergency collaboratively with the robot, 3) take a fire extinguisher and deal with the fire on her own, 4) call the fire brigade. This scenario also was inspired by our previous work presented in [20].

The participant made their choices by telling them to the robot and selecting the choice on the robot's tablet, but neither the robot nor they acted on their choice. They were soon afterwards reassured by the experimenter that there was no real emergency.

[3] The participant were not be invited to go to the kitchen, and the experimenter only pretended that the gas was still on.

[4] NOTE: The emergency situation was a simulation and participants were never in any danger. We played a pre-recorded audio of a fire siren on a speaker in a corner close to the participant. The red colour of a ceiling light in the experimental room was activated by the experimenter using a remote control. In order not to upset the house's neighbours, the alarm sound was played loud enough for the participants to be heard inside the house, but not outside.

We collected their decisions of how they trusted the robot to deal with the emergency scenario.

We also asked participants to complete questionnaires at the beginning and at the end of the study.

A pre-experimental questionnaire for 1) collecting demographic data (age, gender, nationality, job field), 2) the Ten Item Personality Inventory questionnaire about themselves (TIPI) [6], 3) questions to rate their disposition to trust other humans [17], 4) questions to assess participants' previous experience with robots, including what kind of previous interactions and type of robots they interacted with, 5) questions to assess their opinions and expectations with regard to robots (i.e., expectation in receiving help, willingness of having a robot as a home companion, robot's roles [5, 14]), and 5) the Negative Attitudes towards Robots to understand of how robots' behaviours and embodiment were perceived [18].

At the end of their interaction, they completed a post-experimental questionnaire including questions to assess 1) their perception of the interaction (realism) and of the robot (autonomy), 2) robot's perceived reliability, 3) their opinions and expectations with regard to the robot (i.e., expectation in receiving help, willingness of having it as home companion, roles suitable for the robot), 4) the robot's perceived reliability and faith in the ability of the robot to perform correctly in untried situations [15], 5) justifications and reasons for trusting or non-trusting the robot, and 6) the Negative Attitudes towards Robots to understand of how the robot's behaviours and embodiment were perceived. As part of the post-interaction questionnaire, participants were asked by the robot some questions to assess participants' perception of the errors made by the robot during the interaction, and their trust in the robot in different home scenarios.

For this study, we chose the Mojin Robotics Care-O-bot 4 robot[5]. Care-O-bot 4, is a 1.58m tall robot of 140kg. Care-O-bot 4 is a humanoid robot with a omnidirectional base, torso, head, and two arms with grippers. The robot has 29 degrees of freedom, several sensors, Gigabit Ethernet and Wireless connection, 15" touch screen, two 20W speakers and a microphone in the head. Due to these characteristics, the system is suitable for HRI that includes both cognitive and physical activities (e.g. speaking and listening, and manipulating objects).

For this study, we chose the Robot House facility at the University of Hertfordshire's (UK)[6] as the experimental environment to ensure the ecological validity of the study. Indeed, the Robot House provides a very realistic domestic environment suitable for live interactions.

3 Experimental Procedure

Participants were welcomed in the house by the experimenter. On their first day, they were asked to sit at the table to complete the first set of questionnaire. The experimenter introduced briefly the robot by telling the robot's name, and asked participants to keep clear the space around the robot in case it was moving its arms or navigating in the room.

[5] Mojin Robotics https://mojin-robotics.de/en

[6] The University of Hertfordshire Robot House is a four-bedroom British house, fitted out as smart home, equipped with the latest generation of robotics platforms and sensors. robothouse.herts.ac.uk.

Participants were also asked to imagine that they lived with the robot as a companion in their home. After individuals were informed that their sessions were recorded by using ceiling and standing cameras, the experimenter left for the controller room which was hidden from the participants.

On the following days, the experimenter just welcomed participants in the house and left them alone with the robot in the experimental room.

On participants' last day of the study, they were asked to complete the second set of questionnaires. After the trial was concluded, the experimenter heeded individuals' curiosities and observations about the study and the robot.

As part of post-experiment session, participants were debriefed about the fire alarm, the gas and generic consideration and questions about the study. The investigator informed them that the robot's failures were part of the study, and they were reassured that no fire ever sparked in the garage or any part of the house.

4 Participants

We recruited six participants (5 female, 1 male), three for each condition, aged between 24 and 47 (avg. 29.67, st. dev. 8.76). Their nationalities were all different: British, Thai, Romanian, Filipino/Irish, Lithuanian and South African.

5 Results

We evaluated participants' trust in the robot by observing their choice of trusting the robot in the emergency scenario and by analysing their responses through the two sets of questionnaires.

5.1 Trust in Care-O-bot 4

We used qualitative and quantitative data to measure participants' trust in Care-O-bot 4 during the emergency task. Data were collected through the post-study questionnaire, during the observation of the live interaction and the video recordings.

We observed the majority of participants tested with the "big" errors at the end of the interaction (condition **C2**) trusted the robot to be able to handle the emergency fire (2 out 3 participants), while one participant preferred to deal with the emergency situation collaboratively. While participants tested with "big" errors at the beginning of the interaction (condition **C1**) did not trust cob4 (1 out 3 participants) or did not trust neither themselves nor the robot (2 out 3 participants).

In particular, in condition **C1**, the participant who did not trust Care-O-bot 4, insulted the robot by blaming the robot for the emergency. In condition **C2**, the participant who trusted the robot was scared by the fire and rushed towards the house's exit. Another participant, who decided to douse the fire with the robot, asked the robot where the extinguisher was and to call the brigade.

To further understand participants' choices, we coded and categorized for content-analysis their answers given to the open-ended question to explain why they did or did not trust the robot. Participants' responses were then classified to fall into categories that were not exclusive. The categories have been divided in two main hierarchical frames to support differences in sentiment, positive and negative. The positive frame grouped the reasons why people decided to trust the robot Care-O-bot 4 to take care of the fire emergency. In contrast, the negative frame was used to include the motivations that induced the participants to not trust the robot in the same scenario. In Table 1 we identified the categories to code participants' motivations given to justify their trust in Care-O-bot 4.

Table 1: Results of the qualitative analysis of participants' motivation to trust Care-O-bot 4.

Positive Sentiment	Trust in other people: this category coded participants' tendency of relating to robots as they do with other humans. For example, a participant said "I easily trust everyone" and "I believe that people know what they are doing"
Positive Sentiment	Trust gained during the interaction: some participants built their trust in the Care-O-bot 4 during the interaction, forgiving or forgetting the robot's errors. Indeed, some commented "he was correct all the time".
Negative Sentiment	Negative effects of anthropomorphism: we coded in this category the attribution of human traits, emotions, and intentions to the robot. For example, "he is stupid, arrogant and sarcastic".
Negative Sentiment	Criticality of the task: some participants trusted the robot for cognitive and low criticality tasks. Some examples were: "I would trust him with most things" and "I personally trust in robot with regular tasks such as reminding, cleaning".
Negative Sentiment	Trust lost during the interaction: participants justified that they did not trust the robot due to the amount of errors. We coded in this category comments such as "it promised not to tell my secret".
Negative Sentiment	Lack of the robot's reliability: we coded participants' lack of reliability in the robot. Some participant did not trust Care-O-bot 4 because "he would understand my commands correctly" or "the responding of the Care-O-bot was still slow and not precise".

Figure 1 shows the qualitative analysis of participants' responses. We can observe that participants equally trusted the robot to be able to deal with the emergency scenario because it managed to gain their trust during the interaction or they are affected by their attitude of trusting others. On the contrary, participants who believed that the robot had limited capabilities preferred to not trust the robot to be able to handle the emergency unsupervised.

5.2 Antecedents of trust

We tested if participants' choices of trusting the robot during the emergency scenario were affected by their previous experience with robots, personality traits, disposition of trust and perception of robots.

Previous experience with robots The sample of participants consisted of a carer, three PhD students (two of them in Computer Science, and the other in Astrophysics), and two administrative staff. The majority of participants did not have any experience at all

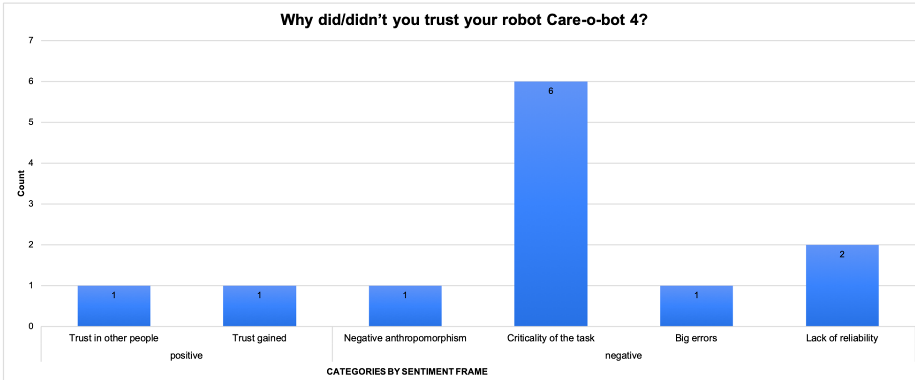
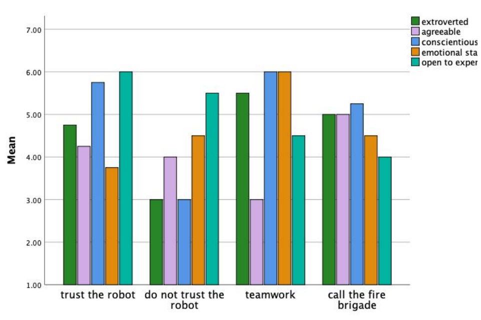


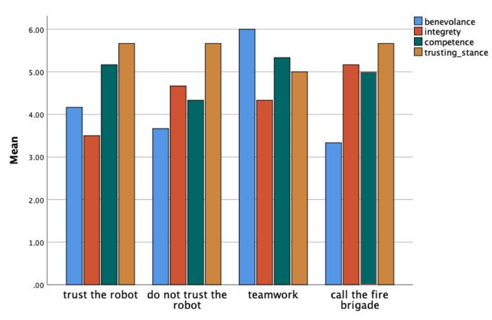
Fig. 1: Summary of the qualitative analysis of participants' responses for the reasons why they did or did not trust the robot Care-O-bot 4. Categories are divided by differences in trusting response, positive and negative.

(2 out 6 participants) or very low experience (2 out 6 participants) with the robot. Those with low experience had been participants in other studies in which they interacted with Softbank Robotics Pepper robot. The remaining 2 participants were researchers in fields close to AI and robotics, who had experience with a Panda robotic manipulator, arm robots and a small mobile robot, called BB8.

Personality traits and Disposition of trust We observed that there were not difference between participant's choice of trust and the distribution of their personalities (see Figure 2a) and their disposition of trust (see Figure 2b). Indeed, even if we acknowledge that the effect of the significance level cannot be assumed with high degree of confidence due the limited sample of participants, we did not find any statistical difference between participant's choice of trust and their personalities ($p >= 0.05$), nor disposition of trust ($p > 0.3$).



(a) *Distribution of personality traits.*



(b) *Distribution of disposition of trust.*

Fig. 2: Distribution of participants' choice of trusting the robot and (a) their personality traits, and (b) their disposition of trust.

Perceptions of robots We asked participants to rate their opinions and expectations with regard to robots (i.e., expectation in receiving help, willingness of having a robot as home companion, robot's roles). We used a 7-points Likert scale where 1 corresponds to "not at all" to 7 "very much".

All the ratings with values less then 4 were categorised as negative response, with values equal to 4 were considered moderate and with values more than 4 were categorised as affirmative responses.

We observed that four people out of six were happy to have a robot as a companion in their home, and they expected help from it in their everyday activity. On the contrary, the remaining two were uncertain in having a robot as companion, and they had low expectations on receiving help from it.

The majority of participants chose as roles perceived as suitable for robots: 1) assistant (2 out 6 participants), 2) tool (2 out 6 participants), 3) companion (1 out 6 participants), and 4) friend (1 out 6 participants).

5.3 NARS Analysis

The NARS scale has been used to understand how people perceive a robot's behaviour and embodiment factors [24]. The scale is composed of 14 items which can be subdivided into three categories: 1) **S1** negative attitude to situations of interaction with robots (six items), 2) **S2** negative attitude towards social influence of robots (five items), and 3) **S3** negative attitude about one's own emotions when interaction with robots (three items). Items are rated by participants on a 5-point Likert Scale where ratings of 1–2 indicate more positive attitudes towards robots, a rating of 3 indicates neutral attitudes towards robots, and ratings of 4-5 indicate greater negative attitudes towards robots.

To measure the internal consistency (or reliability) of the subscales, we performed a Cronbach's Alpha analysis on participant's responses. The analyses were run on the responses to the NARS questionnaire at the beginning and end of the interaction trials, by removing the same items and reversing some other to maintain consistency of the subscales.

The Cronbach's Alpha values of the subscales obtained from the analysis of the post-experimental questionnaire are respectively: S1 - $\alpha = 0.674$, S2 - $\alpha = 0.571$, and S3 - $\alpha = 0.674$.

The overall NARS categories had no statistically significant relationship comparing participants' perception of the robot before and after the interaction trials.

5.4 Post-experimental evaluation

As part of post-experimental questionnaire, people were asked to rate their perception of the interaction and the robot.

Perception of the interaction A 7-point Likert Scale, ranged from 1 to 7 (disagree to agree), was used to measure the participants' judgement of the realism of the scenarios. All participants but one rated the scenarios very realistic (ratings higher than 5).

At the end of the final questionnaire we also asked participants if they believed the robot was behaving autonomously. Half of the participants believed that Care-O-bot 4 is not autonomous (ratings less than 3), one person rated the robot as autonomous (ratings higher than 6) and two were uncertain (ratings equals to 4).

Perceptions of Care-O-bot 4 We asked participants to rate their willingness of having Care-O-bot 4 or another robot as home companion, and the roles suitable for the Care-O-bot 4.

We observed that the majority of participants (4 out 6 participants) were really happy about the idea of having Care-O-bot 4 in their homes, one participant was not inclined to have Care-O-bot 4 as home companion, and the remaining participants did not state to neither want or not want Care-O-bot 4 as home companion. On the contrary, the majority of participants were less enthusiastic (2 out 6 participants) or were not inclined at all of having another robot as home companion (2 out 6 participants).

The majority of participants chose as roles perceived as suitable for robots: 1) assistant (2 out 6 participants), 2) tool (1 out 6 participants), 3) companion (1 out 6 participants, friend (1 out 6 participants) and butler (1 out 6 participants).

We also measured people's perception of the robot's reliability and faith [15] to perform correctly in untried situations using a 7-point Likert Scale [1= disagree strongly and 7= agree strongly].

We observed that the participants' perceived reliability of the robot was lower for participants that chose to trust the robot ($n = 4.17 \pm 0.24$) when tested with condition **C2** than for participants that preferred to call the fire brigade ($n = 6.17 \pm 0.24$) when tested with condition **C1**.

5.5 Errors evaluation

In the last part of the questionnaire the robot asked the participants if it made any errors, to select errors with big and small consequences from a list provided by the robot, and to indicate if they would trust Care-O-bot 4 in other scenarios.

Four out of six participants stated that the robot made errors during the interaction, but, interestingly, two out six participants did not think that the robot made errors. These latter two participants were tested one in each condition.

Table 2 shows the distributions of people's responses by rating the errors obtained from the questionnaire responses. The resulting rankings highlighted three big errors and four small errors. These scenarios also included the big errors used in the interactions (questions **Q1**, **Q2** and **Q4**), participants rated them as errors with severe consequences.

Finally, we investigated whether participants would have trusted Care-O-bot 4 in scenarios different from the fire emergency. They did not trust the robot with life threatening scenarios: 1) they did not trust the robot to deal with an emergency scenario in a place different of garage, 2) they did not trust the robot to look after the well-being of their beloved ones, and 3) they did not trust the robot to take their pet for a walk. In contrast, participants trusted Care-O-bot 4 to be able to handle cognitive and lower risks situations In particular, they unanimously stated to trust the robot to be able to remind them to take medicines, important meetings, and to manage a smart house like the Robot House.

6 Conclusion

With this article, we conducted an exploratory work to investigate whether people's trust in a robot can be recovered more easily when a severe error happens at the beginning or end of a longer-term interaction. In the presented study, a Care-O-bot 4 robot engaged

Table 2: Participants' ratings of big and small errors

Scenario	Big Errors	Small Errors
Q1 You share some private information about yourself with the robot. Your robot reveals it to a visitor.	83.3%	0
Q2 You ask your robot to charge your phone. Your robot puts it in the toaster.	83.3%	0
Q3 You asked your robot to show you the latest news. Your robot shows it on his own screen that faces away from you.	16.7%	100%
Q4 Your robot cooked some biscuits in the oven. It forgot to switch the oven off.	66.7%	16.7%
Q5 You are sitting on the right side of a table, your robot puts your drink on the opposite side.	0	83.3%
Q6 You and your robot are solving a puzzle. You ask your robot to take a piece useful to solve the puzzle. Your robot brings you the wrong piece.	0	83.3%
Q7 Your robot leaves your pet hamster outside the house in very cold weather.You are sitting on the sofa.	83.3%	0
Q8 You ask for a cup of coffee. Your robot brings you an orange.	0	83.3%

participants in several tasks over three weeks. The robot made errors with severe consequences either at the beginning or at the end of its interactions with participants. At the end of the six interaction days participants were tested by observing their choices of trusting the robot or not with regard to its ability to handle a fire emergency in the house.

The majority of participants were female and they did not have any previous experience with robots. People believed that the scenarios were very realistic but most of them did not believe in, or they were uncertain about, the robot's autonomy. This result is particularly interesting because we believe that participants did not think that the robot was tele-operated but they judged its capabilities of handling tasks autonomously [4]. Indeed, while participants were fully immersed in the scenarios, including the fire emergency, they seemed to not expect help from the robot. They principally perceived the robot as an assistant and they believed the robot had limited abilities.

Moreover, this study showed that participants were affected more by robot errors made at the beginning of the interaction than at the end of the interaction. On one hand, this result confirmed our previous findings [21] and it is also supported by other studies where people's impressions of an agent are formed during the first encounters with the robot [25]. On another hand, a further investigation on the reasons causing the lack of people's trust in the robot was also due to the context, and in particular, the criticality of the emergency task. These findings corroborated the evidence that the reliability in robots' capabilities was affected by the risk of a possible negative outcome [16, 13].

Not every participant acknowledged that the robot made errors. However, they all judged the tasks in the interaction as errors with severe consequences. We believe that participants stated that the robot did not do any errors because they were asked directly by the robot. Accordingly, some studies in psychology and human-computer interaction showed that people could feel inhibited to communicate their disapproval to the bystander culprit (i.e., the robot) [3, 28].

Our results are limited by a small sample size and thus need to be consolidated by conducting larger scale trials involving a more general population. However, our findings suggest that some participants do not trust an interactive robot to be capable of handling emergency scenarios or high risk tasks.

ACKNOWLEDGMENT

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 642667 (Safety Enables Cooperation in Uncertain Robotic Environments - SECURE). KD acknowledges funding from the Canada 150 Research Chairs Program.

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